# Study of fusion-fission dynamics through fission fragment angular and mass distributions

S. Appannababu*
Department of Physics, Faculty of Science,
The M. S. University of Baroda, Vadodara - 390002, INDIA

Several experimental efforts has been going on, in the investigation of the formation of super-heavy nuclei. Such experiments are extremely challenging as the formation of heavy/super-heavy elements are heavily suppressed not only by equilibrium fission, but also by a non-equilibrium process called quasi-fission (QF)[1, 2]. The experimental problem is to identify those variables that hinder compound nucleus formation which can lead to a super heavy element formation. This can be addressed by measuring the characteristics of the fusion, fission and non-equilibrium fission events. The entrance channel properties of the reacting system appears to play a major role in the nuclear reaction dynamics of non compound nucleus fission, in particular the entrance channel mass-asymmetry. The entrance mass asymmetry of the interacting projectile-target combinations decides the direction of the mass flow in the di-nuclear system in either way. Earlier dynamical models predicted that QF occurs when $Z_pZ_t \geq$ 1600 but recent results shows that the onset of QF starts at $Z_pZ_t$ value equal to nearly 1000 and plays a dominant role at higher values of $Z_pZ_t$[1]. It is also important to understand how the static deformation of the target/projectile, their spins and the product of $Z_pZ_t$ effects this fusion-fission process.

It is well established that one can infer the occurrence of QF by measuring the evaporation residue (ER) cross sections, fission fragment angular distributions and mass distributions. Recently there is a lot of interest in the study of fusion-fission dynamics in less fissile systems due to the observation of several interesting results. The observation of the unexpected presence of quasi-fission in reactions forming compound systems as light as $^{216}$Ra has become a matter of intense investigation with less asymmetric systems like $^{19}$F + $^{197}$Au[3]. The study of fusion-fission dynamics in the medium mass region A≈200-220 is very interesting due to the observation of many unexpected results, even though the reactions studied are having similar $Z_pZ_t$ values. It appears that in these less fissile systems, the relaxation of mass is slower than the relaxation in K degrees of freedom, which is in contradiction to heavier and highly fissile systems. Thus, it becomes imperative to understand the relaxation mechanism of various degrees of freedom in detail, in less fissile systems. In this context we have studied different systems populating $^{213,215}$Fr compound Nucleus (CN) through fission fragment angular and mass distributions, which is very much similar to the previously studied CN $^{216}$Ra[3], to understand the various degrees of equilibration in less fissile systems[4, 5].

Recently there is a lot of interest in the study of fusion-fission dynamics with stable weakly bound nuclei due to the observation of fusion enhancement/suppression around the Coulomb barrier, and to understand the effect of breakup channel on reaction mechanism. It is very important to understand the fusion-fission dynamics with stable weakly bound nuclei, in order to understand the behavior of the fusion-fission process induced by radio active halo nuclei which are having similar nuclear structure. Recent experimental results shows that there is either the enhancement of the fusion cross sections due to the coupling to the break-up channels or there is fusion hindrance due to the loss of incident flux due to the breakup. The effect of the break-up on

*Electronic address: appannababu@gmail.com

the fusion cross-section seems to be different at sub-barrier and above barrier energies, with fusion enhancement at below barrier energies and fusion suppression at above barrier energies. It is reported that with heavier targets that the incomplete fusion channels are most favorable at energies around the Coulomb barrier due to the breakup effects. It is also important to understand the role of the nuclear and Coulomb break-up with different targets. The small breakup threshold energy of $^{9}$Be into $^{8}$Be + $^{1}$n (1.67 MeV) and/or into $^{5}$He + $^{4}$He (2.55 MeV), makes it interesting to study the reactions induced by weakly bound projectiles. In order to investigate the effect of break-up on fission fragment angular distributions, we have studied the reaction $^{9}$Be + $^{232}$Th around the Coulomb barrier energies[6]. The experimental results are compared with various standard theoretical models.

In summary, we have studied fission fragment angular distributions for the CN $^{215}$Fr, fission fragment mass angle correlations, mass ratio distributions for the CN $^{213}$Fr and fission fragment angular distributions for the reaction $^{9}$Be + $^{232}$Th, results will be discussed in the symposium.

## Acknowledgments

The author acknowledges IUAC and CSIR for financial assistance for the present work. We also acknowledge the support received from pelletron staffs at IUAC and TIFR-BARC pelletrons. We acknowledge target and vacuum labs at IUAC.

## References

[1] W. J. Swiatecki, Phys. Scr. **24**, 113 (1981).
[2] J. P. Blocki *et al.*, Nucl. Phys. A **459**, 145 (1986).
[3] A. C. Berriman *et al.*, Nature (London) **413**, 144 (2001).
[4] S. Appannababu *et al.*, Phys. Rev. C **80**, 024603 (2009).
[5] S. Appannababu *et al.*, DAE Symp. on Nucl. Phys. **54**, 352 (2009).
[6] S. Appannababu *et al.*, DAE Symp. on Nucl. Phys. **54**, 340 (2009).